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Cost and Performance Report

(UX-0105)

A Fast 4-D TEM System for UXO Characterization

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ACRONYMS AND ABBREVIATIONS

APG	Aberdeen Proving Grounds
ATC	Aberdeen Test Center
BOR	body of revolution
CFG	configuration
DNT	Dynamic NanoTEM
EM	electromagnetic
EMI	electromagnetic induction
EOD	explosive ordnance disposal
ESTCP	Environmental Security Technology Certification Program
FDEM	frequency domain electromagnetic
GPS	global positioning system
GX	Geosoft executables
H&S	health and safety
HAZWHOPER	Hazardous Waste Operations and Emergency Response
MSHA	Mine Safety and Health Administration
MTADS	Multi-Sensor Towed Array Detection System
NSR	noise/signal ratio
P_d	probability of detection
QC	quality control
ROC	receiver operating characteristic
RTK	real time kinematic
SERDP	Strategic Environmental Research and Development Program
SNR	signal-to-noise ratio
TEM	time domain electromagnetic
USACE	U.S. Army Corps of Engineers
UTM	universal transverse Mercator
UXO	unexploded ordnance

ACRONYMS AND ABBREVIATIONS (Continued)

UTC	coordinated universal time
YPG	Yuma Proving Grounds

ACKNOWLEDGEMENTS

The configuration of Zonge Engineering's NanoTEM® system for use in UXO detection and discrimination and the development of supporting data processing software have been supported by the Environmental Security Technology Certification Program (ESTCP). The entire project was managed by Zonge Engineering under the direction of D. D. Snyder, acting as the Principal Investigator.

In the early stages of the project, David C. George with G&G Sciences (Grand Junction, CO) helped Zonge plan our system data processing. It was Dave who persuaded us to develop our software around Geosoft's Oasis Montaj. Dave helped us through the initial testing of our acquisition software, assembled the Oasis-based prototype data processing system, and participated in our predemonstration activities at Blossom Point. He was a major contributor to the progress report that we submitted to ESTCP describing the Blossom Point demonstration. Scott C. MacInnes, Principal Scientist, developed all our interpretation software. He perfected and expanded the basic data processing software and was a major contributor to our final report. Scott's contributions to the overall success of this project cannot be overestimated. Jennifer L. Hare, senior scientist, made important contributions during the preparation of our final report.

Zonge gratefully acknowledges the support of the ESTCP program and, in particular, the encouragement and patience of its director, Dr. Jeff Marqusee, and the ESTCP UXO Program Manager, Dr. Anne Andrews. Without the support of the ESTCP program, the DNT system described in this report would not now be a reality.

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1.0 EXECUTIVE SUMMARY

Electromagnetic induction (EMI) sensors are effective for the detection of unexploded ordnance (UXO) and other shallow-buried metallic objects because of their high electrical conductivity and magnetic permeability relative to that of the host medium. But neither frequency domain EM (FDEM) instruments that measure a single frequency nor time domain electromagnetic (EM) (TEM) instruments measuring the secondary EM transient over a single time window provide sufficient information to permit reliable classification or identification of target response. Consequently, during clearance operations, all metallic targets must be visually identified. Since each such target is potentially a piece of UXO, these targets must be identified by explosive ordnance disposal (EOD) specialists at an average cost that exceeds $100 per target.

Current research in applying EMI to UXO detection is directed towards the development of new instruments and data processing techniques that promise to improve our ability to classify or otherwise identify a target as either UXO or clutter. In data processing and interpretation, research has been directed toward the development of physic-based models that help to classify targets according to shape characteristics extracted from the spatial behavior of the EMI response [3, 4]. Using a model based on a point dipole, these techniques have been shown to be effective in discriminating targets having UXO-like characteristics such as an axis of symmetry and aspect (i.e., a large length-to-diameter ratio). However, reliable model results can be obtained with this type of analysis only with a very high density of data points in the immediate vicinity of the target (usually within a radius of 1 m of the anomaly center). With conventional EMI instruments such as the EM-61, the required data density is obtained by surveying the area under investigation in two orthogonal directions at lane spacings of 0.5m. New instruments are being developed that sample the EM response at either multiple frequencies or multiple time windows of the decay transients. These new instruments exploit the fact that the shape of the transient decay or its equivalent frequency spectrum provides important clues about the characteristics of the target.

The Zonge Dynamic NanoTEM (DNT) system that we have demonstrated with the support of the Environmental Security Technology Certification Program (ESTCP) program is an effort to improve on the current state-of-the-practice for using EMI induction to detect and classify UXO. The system has three features that help to improve its performance for both detection and classification:

Fast Current Shut-Off Time – Current shut-off time (sometimes called "ramp" time) controls system bandwidth. While transmitting a smaller current, the DNT system is able to shut the transmitter current off 10 times faster (10µs versus 100µs for the Geonics EM61) thus permitting measurements at earlier times where the signal-to-noise ratio is better.

Multiple Time-Gate Transient Sampling – The DNT system samples the EM transient signal at 31 time gates or windows after current shut-off. The system is one of three broadband systems

currently being evaluated that are capable of sampling the shape of the transient decay waveform or its Fourier spectrum.[1]

Multiple Component Data Acquisition – Unique among its competitors is the capability of the DNT system to simultaneously acquire TEM transient data from three independent receiver antennas. In this demonstration, we deployed an array of three receiver antennas oriented along the three principal axes of the antenna cart. The main advantage of the multiple channels is that they triple the amount of independent data acquired at each spatial field point.

The objectives of our demonstration are manifold. In our predemonstration conducted at Blossom Point, our objectives were to show that the system was operational and ready for a more formal demonstration that was ultimately conducted at the Standardized UXO Technology Demonstration Site at the Aberdeen Proving Grounds (APG). The formal demonstration at APG showed that the DNT system can be deployed under realistic field conditions and that we can economically acquire and process high quality "4D" EMI data. As part of the APG demonstration, we submitted target lists for both the blind test grid (0.2 has 400 target sites) and the open field area (~6 ha – 1601 targets reported). We believe that all the objectives for the DNT system going into the demonstration have been met.

During the demonstration at APG, we showed that we can survey large areas at 0.5m lane spacings at the rate of better than 0.4 ha (1 acre) per day. Our probability of detection (P_d) in the response stage was 80% overall for the blind test grid [2]. The corresponding performance degraded significantly in the open field (to 45% overall) according to scores received from ATC [1]. We do not have a satisfactory explanation for this performance degradation. According to Larry Overbay, who is in charge of the Standardized Test Site at Aberdeen, the degradation in scores between the blind test grid and the open field is consistent with scoring results from other demonstrators [5]. Both the blind test grid and the open field response stage scores show that the DNT system performance is best for shallow targets (< 0.3m), and is degraded for targets at intermediate depths (0.3-1 m). The system cannot reliably detect targets at depths greater than 1m.

Based on their analyses of our open field target submittals, ATC attributes the low scores primarily to our having missed detecting many pieces of small ordnance at shallow depths. That explanation stands in direct contradiction to the scoring from the blind test grid where we successfully detected 100% of the shallow (< 0.3m) targets. Until we have access to the APG ground truth, we are unable to explain this contradiction.

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[1] The Geonics EM63 is a TEM instrument that samples the decay waveform at 26 time gates. The Geophex GEM-3 is an FDEM instrument that can sample the spectrum at multiple frequencies over a broad spectral range.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

DNT is a system for the dynamic acquisition of TEM data. The system is based on Zonge's proprietary NanoTEM® system for acquiring multigate (i.e., 31 gates) TEM decay transients for shallow mining, environmental, and engineering problems. Developed more than 10 years ago, the basic system has been successfully applied worldwide. With modified acquisition software and a specially designed antenna cart, we have configured the NanoTEM system for application to UXO detection and classification. We show a simplified block diagram of the DNT system in Figure 1.

Figure 2 is an annotated photograph showing the DNT system in operation at Blossom Point. The photo principally shows a cart-mounted antenna array consisting of a 1m x 1m transmitter loop (green) together with 3 orthogonally oriented receiver loops (blue, yellow, red). The instrument package (not shown) is carried on a pack frame worn by one of the operators. The antenna cart has been designed for detection of metal objects such as UXO to depths of up to a meter.[2] Because the DNT system is a "fast" turn-off TEM system, it is particularly well suited for detection of small shallow objects.

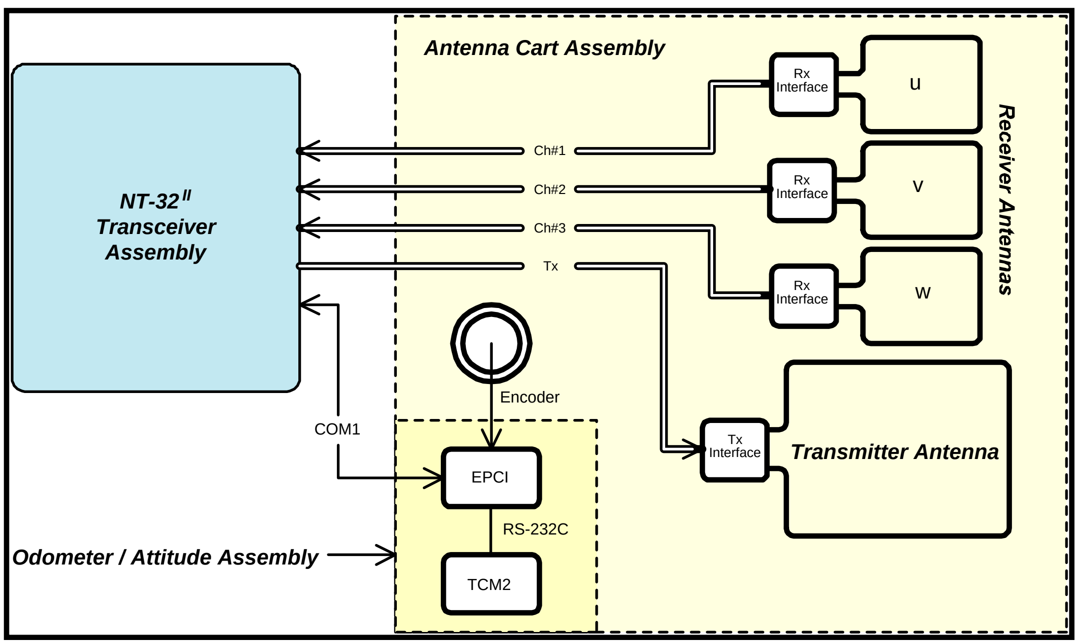

Figure 1. Block Diagram of the DNT System.

As deployed for the demonstrations mentioned in this report, DNT samples the secondary field transients induced in each of the three receiver antennas mounted on the antenna cart. The

[2] The maximum depth of detection depends on many factors, not the least of which is target size. In the Calibration Lanes at APG and at the Blossom Point site, no target deeper than 1m was detected. Targets such as the 60mm M49A3 mortar are detectable at 75cm depth. Common artillery projectiles such as the 105mm M60 and the 155mm M483A1 are close to their maximum detection depths at 0.9m (depth to nearest point).

standard DNT acquisition program transmits bipolar current pulses with a 50% duty cycle and a base period of 32Hz (Figure 3). After the current has been completely turned off (about 10 μs) the resulting transient decay curves are sampled out to 2,457 μs at a sample interval of 1.2 μs (2,048 samples). The uniformly sampled transients are then composited into 31 gates or time windows with centers located at approximately logarithmic time intervals over the interval from less than 1.2 μs after the end of the current turn-off ramp, out to a time of 1,910 μs. In this *profile* mode of acquisition, DNT acquires 32 transients per second on each of three separate receiver channels. The location of the 31 standard NanoTEM transient windows is shown in Figure 4. Early gates are composed of single samples. Later gates are computed as the average of all samples within a given interval. The center of each window is given as the geometric mean of the starting and ending window times.

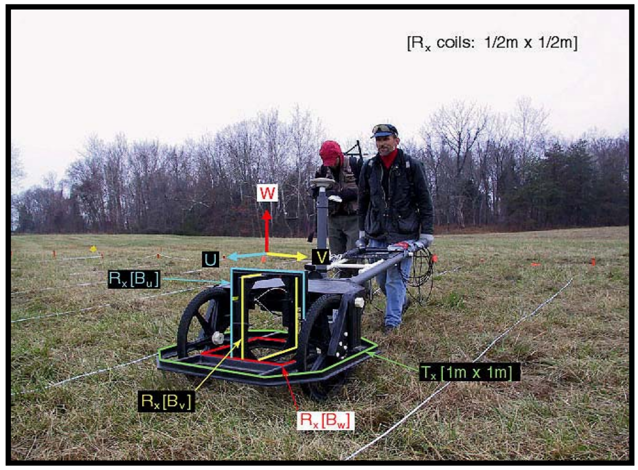

Figure 2. Photograph Showing DNT Antenna Cart. (Blossom Point, December 2001)

Each transient is time-stamped with coordinated universal time (UTC) time that is read from a real-time clock having sub-second resolution (1/32 sec).[3] We electronically synchronize the

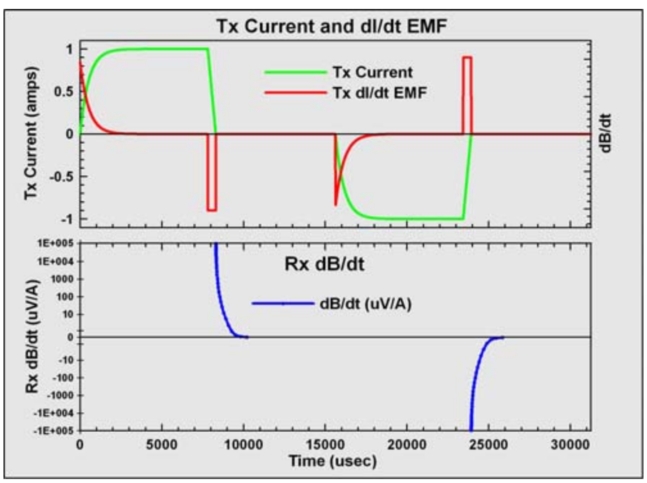

Figure 3. DNT Transmitter Waveform (Green), the Electric Field in the Target (Red), and the Secondary Transient (Blue) Induced in the Receiver Antenna.

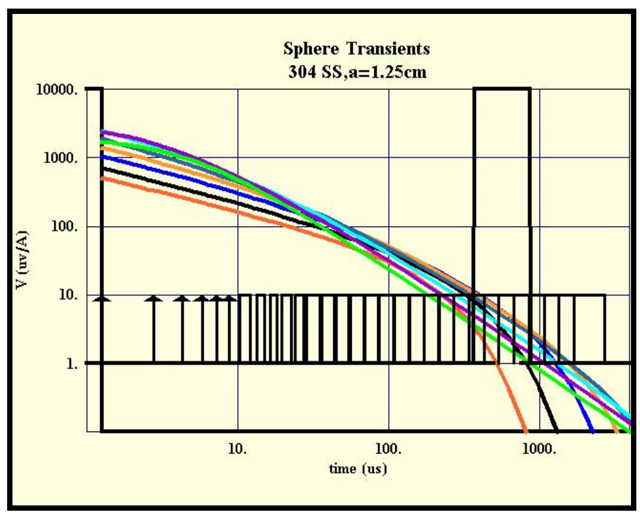

Figure 4. Location of the 31 DNT Time Gates. (The transient curves are for a conductive permeable sphere with different magnetic permeabilities. The large gate is the standard EM61 time gate.)

[3] We have recently upgraded the sub-second resolution of our real time clock to 1/256 sec (~4ms).

real-time clock to UTC using a Motorola universal transverse Mercator (UTM) with global positioning system (GPS) engine and special software. Timing synchronization is better than 1 ms. The resulting transient data with time stamps are stored on a hard disk in the Zonge NT-32II transceiver. Antenna positions are recorded separately using a Leica SR530 real time kinematic GPS system.

We have developed a software system for processing and interpreting these data. It is beyond the scope of this report to describe that software in detail. The reader is referred to the final report for this project for the details [6]. The software system Dynamic Nano Tem System (DNTSys) is built around Geosoft's Oasis Montaj. It includes several standalone programs that are loosely coupled to Oasis together with numerous Geosoft executables (GX) that augment and customize the standard capabilities of Oasis for processing line-oriented survey data.

2.2 PROCESS DESCRIPTION

All necessary gear for conducting a DNT survey can be transported to a job site by airfreight or overnight package carrier (e.g., UPS or FedEx). For our demonstrations at Blossom Point and APG, shipping weight was approximately 750 lbs. The equipment can be parceled into packages that meet the weight and dimensional requirements to be handled by the overnight package carriers. Once on site, the gear can be assembled in a matter of a few hours.

Small DNT surveys can be conducted with two people. However, for larger surveys such as the demonstration at APG, it is more efficient to use three or even four people. One operator carries the GPS receiver and pushes or pulls the antenna cart. A second person carries the NT-32II TEM transceiver electronics package and takes notes. Both operators are tethered to the cart by the cables required to make connection with the TEM transmitter and receiver antennas and with the GPS antenna. When available, the third person is used to position lane marker tapes ahead of the survey and to perform preliminary data quality control (QC) during the course of the survey. With three or more people involved, the DNT system can be kept surveying virtually 100% of the time on site. Data are collected along a series of parallel lines at 0.5m intervals. The 0.5m line spacing is required if the data are to be processed and interpreted with our model-based interpretation software (DNTDipole). Using a three-man crew and surveying large areas with a 0.5m line spacing, we can cover an average of 0.4 ha/day (1 acre/day).

DNT performance was graded over both the blind test grid and the open field at Aberdeen. The performance for the two areas is summarized, respectively, in Table 1 and Table 2. Since the DNT system was the first to be demonstrated at the newly constructed Aberdeen demonstration site, we have no baseline system with which we can compare our results. It is clear from these results that the overall P_d for the response stage is biased downward by poor performance in detecting targets buried deeper than 1m. With regard to the discrimination stage performance, we can only state that the principal objective we had for the ESTCP project was to demonstrate the hardware system and not to demonstrate an advanced system for target classification. We had 30 days after the completion of our field demonstration in which to submit our target lists for both stages of scoring. Although we had developed model-based interpretation software (DNTDipole) and indeed we used it to help us discriminate our response stage target lists, we were low on the learning curve in applying the tool. Since that time we have refined our ability to interpret the target parameters that are generated by DNTDipole. We have prepared a revised

target list for the Blind Test Grid wherein the target discrimination stage has been revised using multivariant statistical analysis techniques that we described in our final report [6]. We plan to resubmit the revised target list to Aberdeen for rescoring. We trust when this revised list is rescored, the results in the discrimination phase will significantly improve.

Table 1. Performance Summary—APG Blind Test Grid [2].

				By Size			By Depth (m)		
Metric	**Overall**	**Standard**	**Non-Standard**	**Small**	**Medium**	**Large**	**<0.3**	**0.3 to <1**	**>=1**
Response Stage									
P_d	0.80	0.90	0.65	0.90	0.70	0.90	1.00	0.80	0.10
(P_d Low 90% Conf)	0.75	0.83	0.53	0.82	0.55	0.66	0.95	0.68	0.01
P_{fp}	0.90	--	--	--	--	--	0.90	0.90	1.00
(P_{fp} Low 90% Conf)	0.85	--	--	--	--	--	0.81	0.81	0.56
P_{ba}	0.50	--	--	--	--	--	--	--	--
Discrimination Stage									
P_d	0.45	0.50	0.35	0.45	0.40	0.50	0.55	0.40	0.00
(P_d Low 90% Conf)	0.38	0.41	0.25	0.32	0.30	0.27	0.48	0.30	0.00
P_{fp}	0.50	--	--	--	--	--	0.50	0.45	0.50
(P_{fp} Low 90% Conf)	0.42	--	--	--	--	--	0.42	0.35	0.14
P_{ba}	0.00	--	--	--	--	--	--	--	--

Response stage noise level: 0.00
Recommended discrimination stage threshold: 50.00

Table 2. Performance Summary—APG Open Field [1].

Summary of Open Field Results for 4-D TEM

				By Size			By Depth (m)		
Metric	**Overall**	**Standard**	**Non-Standard**	**Small**	**Medium**	**Large**	**<0.3**	**0.3 to <1**	**>=1**
Response Stage									
P_d 0.45		0.50	0.40	0.40	0.55	0.50	0.60	0.45	0.05
(P_d Low 90% Conf)	0.43	0.47	0.33	0.33	0.49	0.41	0.57	0.41	0.03
P_{fp} 0.45		--	--	--	--	--	0.40	0.45	0.25
(P_{fp} Low 90% Conf)	0.41	--	--	--	--	--	0.39	0.42	0.11
BAR 0	.15	--	--	--	--	--	--	--	--
Discrimination Stage									
P_d 0.30		0.35	0.25	0.15	0.40	0.35	0.35	0.35	0.05
(P_d Low 90% Conf)	0.26	0.28	0.20	0.12	0.36	0.29	0.30	0.29	0.01
P_{fp} 0.30			--	--	--	--	0.30	0.30	0.20
(P_{fp} Low 90% Conf)	0.29		--	--	--	--	0.27	0.29	0.07
BAR 0	.05	--	--	--	--	--	--	--	--

Recommended discrimination stage threshold: 50.00
Note: The recommended discrimination stage threshold values are provided by the demonstrator.

A three-man DNT crew suitable for conducting extended DNT surveys should include a crew chief, a field hand, and a geophysicist. A Zonge crew chief is trained in all aspects of the field operation, including operating the DNT acquisition system and the GPS system. In addition to being able to perform all the tasks of the crew chief, the geophysicist must be capable of performing all data processing tasks necessary to QC the data. All Zonge field personnel must be current with both their Mine Safety and Health Administration (MSHA) and Hazardous Waste Operations and Emergency Response (HAZWHOPER) training.

Zonge field crews operate under a general health and safety (H&S) plan that is reviewed in detail during annual training for Zonge field personnel. We append site-specific requirements to the general H&S. Relevant aspects of the general Zonge H&S plan and any site-specific requirements or plans are reviewed prior to job mobilization and during "tail-gate safety meetings" held while on the job.

The DNT system is only incrementally more complex to operate than the Geonics EM61 MkII that we regard as the baseline system for comparisons. Like the Geonics equipment, experienced field technicians can become competent operators within a day. Naturally, it takes some time and experience to become familiar enough with the instrument to trouble-shoot and diagnose problems. Although our crew chiefs usually have a college degree, few are formally trained in either geophysics or electronics.

2.3 ADVANTAGES AND LIMITATIONS OF DNT

The NanoTEM system was designed to generate and measure secondary transient fields over the time bandwidth ranging from $1 \leq t \leq 2000$ μs. Through the use of fast current switching technology, NanoTEM has demonstrated that it has a sensitivity that is comparable to that of the EM61 metal detector for UXO targets categorized as small ordnance (i.e., < 40mm), medium ordnance (40mm< size < 81mm), and large ordnance (> 81mm). It has significantly more sensitivity to small conductive and nonpermeable objects. It does this with a transmitter moment (i.e., moment = Tx Area * turns * Current) that is only about one-tenth that of the EM-61[4]. However, DNT is presently unable to measure transients at time delays beyond approximately 4 ms. For very large targets (e.g., 155 mm, 6-in, and 8-in artillery projectiles), the principal time constants are more than 10 ms. The so-called late-stage of the transient decay is an important parameter for discrimination [7]. If the measurement of transients beyond the 4 ms limitation of the present DNT system is essential, as it appears to be for large targets, then the present DNT system will require further modification to measure transients over a longer time period.

Perhaps the biggest advantage of the NanoTEM system is its flexibility and its multichannel capability. The system is easily adapted for unusual applications. Surveys conducted in Gambell, Arkansas, and for the City of Tucson illustrate the adaptability of the system [8, 9]. The multichannel capability of NanoTEM makes the system ideal for towed array survey systems similar to Multi-Sensor Towed Array Detection System (MTADS) having a single transmitter loop and up to three receiver loops in any arbitrary configuration.

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[4] Others have estimated the moment of the EM61 to be 200-250 A-m^2. Based on self-inductance measurements on the EM-61 Tx coil, we estimate that the EM61 transmitter has 30 turns and hence a moment of 180 A-m^2 when transmitting 6 A. The transmitter moment of our 8-turn DNT Tx transmitting 3 A is 24 A-m^2.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Our demonstration at APG was conducted at the newly constructed Standardized UXO Technology Demonstration Site [10]. This site was constructed specifically to provide a site where UXO detection and classification technology can be exhaustively tested under realistic conditions. Our performance objectives are listed in Table 3. Our basic qualitative objective has been, and continues to be, to demonstrate that the NanoTEM system compares favorably with competing technology such as the Geonics EM61 for UXO detection. Secondly, we hope to demonstrate that this fast multicomponent, multigate TEM system can provide useful parametric information to aid in target characterization and classification. To achieve this goal, we believe that it is necessary to demonstrate not only our ability to acquire DNT data in an efficient, cost-effective manner, but also on our ability to process, display, and interpret these data efficiently. Table 3 contains quantitative performance objectives that serve to measure how well we met these objectives.

Table 3. Quantitative Performance Objectives for the DNT Demonstration at Aberdeen.

Performance Objective	Performance Metric	Actual Performance
1. Survey productivity	¾ acre/day	1 acre/day
2. Detection efficiency (P_d)	> 90% POD	80% (blind test grid)
3. Discrimination	?	45% (blind test grid)
4. Classification	?	13.9% (blind test grid)

A method for reliable classification of target anomalies is the ultimate goal and indeed the primary justification for introducing new or improved technology such as DNT. Therefore, during the life of this project we have pushed to develop interpretation tools such as our dipole-modeling program, DNTDipole, to support the ability of the DNT system to acquire multicomponent transient data. While we believe we have been very successful in demonstrating all our tools for data processing and interpretation, an important element in achieving our goals in Classification is experience in interpretation using these tools. At Aberdeen, DNTDipole was being developed and modified even as we were trying to meet a 30-day deadline to submit our target lists for scoring. Therefore, to the extent that we did not meet our goals in classification, the responsibility should not be placed on a failure in the basic technology. We submit that, as our experience with using these tools grows, so too will our performance in classifying targets.

3.2 SELECTING TEST SITES

To meet the overall objectives of our project, we require areas that have been seeded with a variety of UXO and clutter objects and for which the ground truth (i.e., the target identity, position, and attitude) have been carefully recorded. Both the NRL Blossom Point site and the Aberdeen site meet this criterion. The Blossom Point site is a relatively small rectangular-shaped area consisting of a grid of 6m x 6m test cells for which ground truth is available to the demonstrator. Most of the targets generate anomalies with good signal-to-noise ratio (SNR) so that target detection is not an issue. The site has been well graded and maintained in an effort to provide an opportunity to acquire data over the site quickly and efficiently. By contrast, the Aberdeen site has an area of nearly 20 acres, some of which present extreme challenges for

surveying. By and large, however, the bulk of the site (more than 15 acres) is accessible to man-portable, cart-mounted survey platforms such as the DNT system supported with real time kinematic (RTK) GPS positioning. A demonstration at the Aberdeen site, therefore, provides an opportunity to test and evaluate the performance of UXO technology under realistic conditions in four phases of its operation: 1) in its operational or data acquisition phase; 2) in its detection phase; 3) in its discrimination phase, and 4) in its classification phase.

From our viewpoint, it is unfortunate that most of the ground truth at Aberdeen remains unavailable to the demonstrator. With the exception of a small area (calibration lanes), the Aberdeen Test Center (ATC) will not disclose the ground truth. The demonstrator, therefore, can evaluate his UXO technology only in the context of the score resulting from the submission of a list of targets detected, their locations, and their discrimination (i.e., UXO/clutter). It is our opinion that the design of the Calibration Lanes is significantly flawed. The purpose of a Calibration Grid is presumably to provide the demonstrator the opportunity to survey test objects identical with those that will be encountered in areas where the ground truth remains unavailable. The Calibration Lanes do contain a good variety of objects placed at different attitudes and depths, but many have been placed at depths where they are undetectable with the DNT system. Even at the shallower depth, many of the targets have a low SNR—too low for reliable modeling. The Calibration Lanes should provide the demonstrator with a good look (i.e., a high SNR anomaly) for each target at least at its minimum depth.

3.3 SITE HISTORY/CHARACTERISTICS

The standardized demonstration site at Aberdeen was constructed in 2001 and 2002 with the U.S. Army Corps of Engineers (USACE) taking the lead. A similar facility is currently being constructed at the Yuma Proving Grounds (YPG) near Yuma, Arizona [11]. Both ESTCP and SERDP have supported the project. The APG site was formerly used for many purposes related to testing ordnance. After the site was designated for use as a standardized demonstration site, it underwent a thorough decontamination that involved phases of detection with magnetometers and EMI followed by retrieval and deactivation or destruction of the resulting objects whenever necessary. The mostly clean site was then seeded with 14 types of standard (inert) ordnance items and an unspecified number of types of clutter and non-standard ordnance. The site is maintained by the Aberdeen Test Center and is available for use under ground rules established by the program and published on the program's Web site (http://aec.army.mil/usaec/technology/uxo03.html) [12]. Figure 5 shows a satellite photograph of the demonstration site. We have annotated the figure to show all areas surveyed during the demonstration by Zonge.

Figure 5 has 12 subareas identified with numbers. Subareas 1-5 are part of a well-graded area that includes the Calibration Lanes (Area 1), the Blind Test Grid (Area 2), and the Mine Field (Area 3). For the purpose of scoring, areas 3-12 were composited together and comprised the Open Field Area. Except for subareas 3, 4, and 5, located within the graded portion of the demonstration site, the Open Field Area was ungraded. From a distance, the Open Field Area appeared relatively smooth. In reality, it was often difficult to walk at a normal pace. We think that the Open Field Test area provided very realistic survey conditions under which to test the mechanical reliability of the cart-mounted antenna array and the overall system performance.

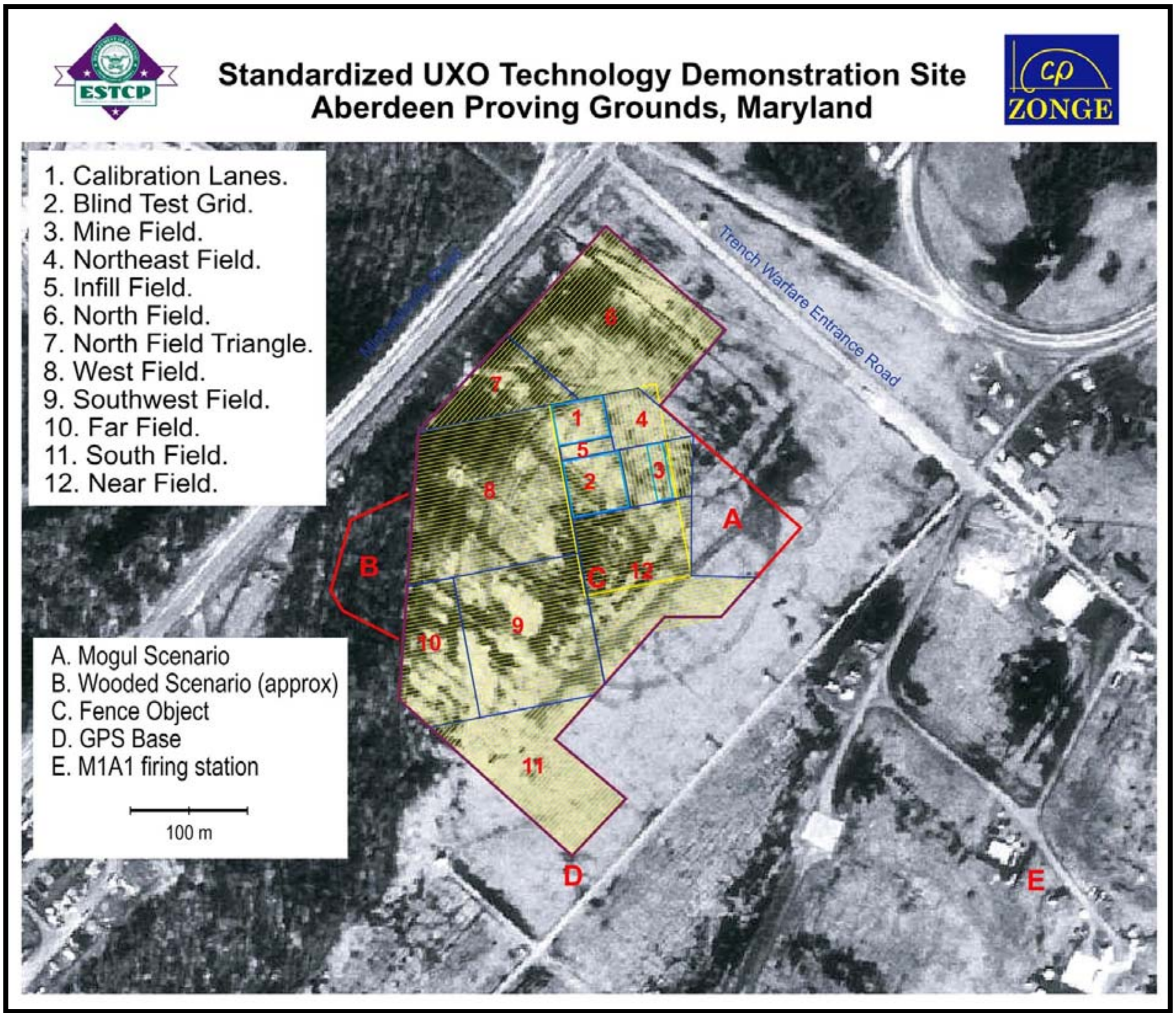

Figure 5. Satellite Photograph (1m resolution) **Showing the Outline of the ATC Standardized Test Site.** (The figure identifies the surveyed grids by number and other areas or features of interest by letter.)

3.4 PHYSICAL SETUP AND OPERATION

The Gantt chart in Figure 6 shows the timeline for activities involved with mobilization, fieldwork, and demobilization. We assembled equipment and field-tested it on August 12-13. We shipped 765 lbs (4 boxes) of gear on Wednesday, August 14, for arrival at the Aberdeen Proving Grounds on Friday, August 16. The crew traveled on Saturday, August 17. On Sunday, August 18, we familiarized ourselves with the area around Aberdeen, purchased field supplies, and reviewed our demonstration plan. We arrived at the APG Visitor Control Building (Bldg 379) at 7:00 a.m., signed in, received badges, and received a safety briefing. After picking up our gear at the APG freight warehouse, we proceeded directly to the field site, arriving at approximately 8:00 a.m.

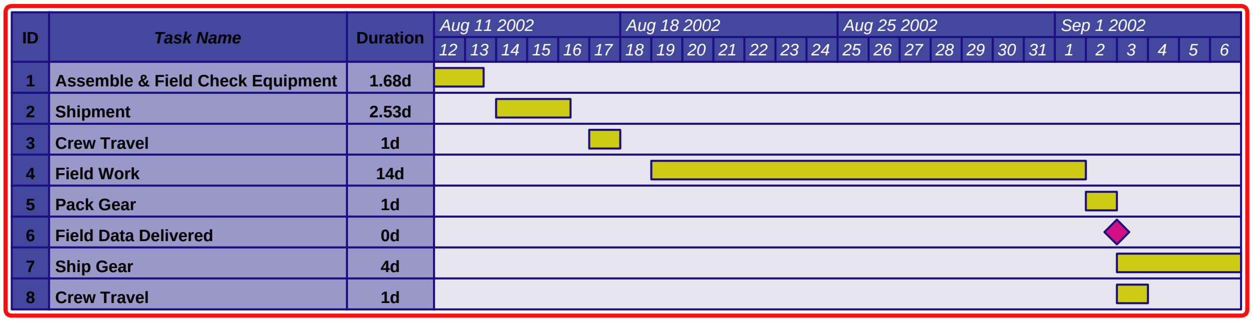

Figure 6. Gantt Chart Showing Schedule of Demonstration Activities.

It took approximately 2 hours to assemble the antenna cart and perform functional tests of our receiver. We set up our battery chargers in the support trailer immediately east of the test site. The only utility required for the operation of the DNT system is 110-220 VAC 50/60 Hz used to charge batteries. Although not absolutely necessary, it is convenient to have access to power and a place to store gear near the field site. That eliminates the need to transport all gear back and forth between the field site and the hotel. At Aberdeen, the only piece of gear we transported back to the hotel after work was the NT-32II transceiver. We had a problem with getting our GPS system operational and lost a few hours while we troubleshot that problem. However, we were operational by early afternoon of our first day on site. We surveyed the Calibration Lane area on the afternoon of the first day and we were able to provide a preliminary color map (Figure 7) to George Robitaille and other visitors the next day.

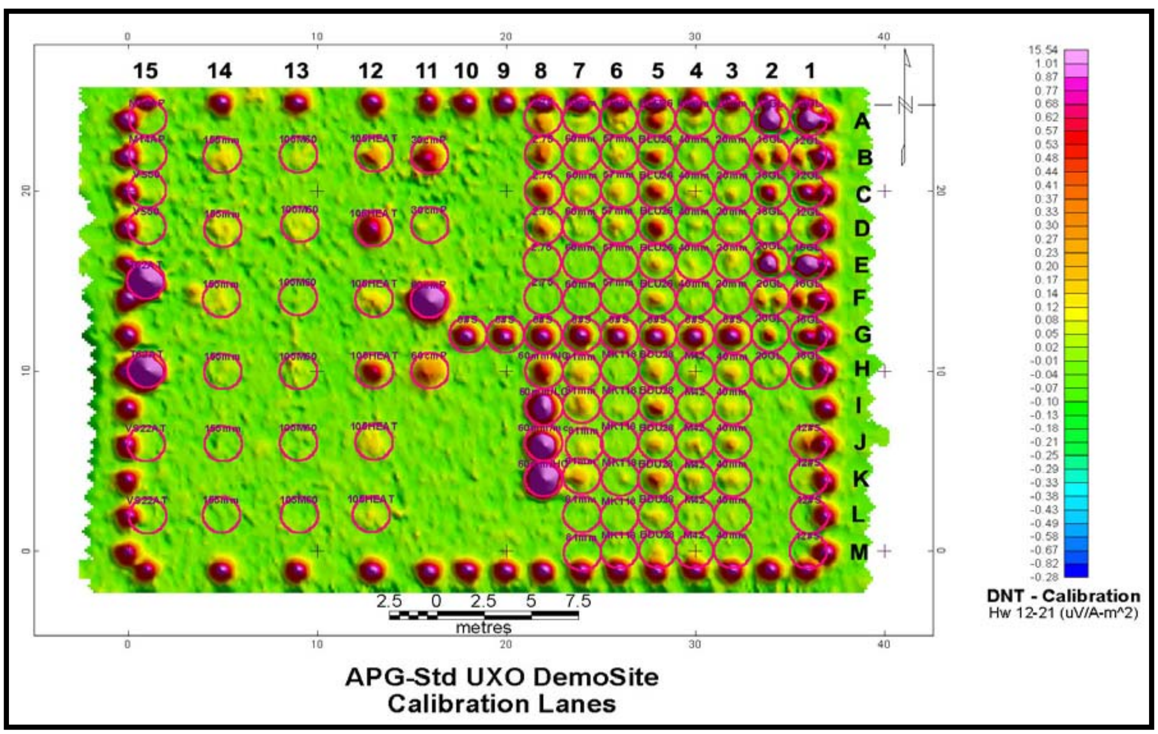

Figure 7. Color Intensity Map of the Calibration Lane Grid at the APG Standardized Test Site.
(Target locations have been marked and annotated with an identity abbreviation.)

3.5 ANALYTICAL PROCEDURES

Our main objective for this demonstration was to conduct a survey over the entire Open Field Area with sufficiently dense coverage to permit us to submit a target list that included classification of the targets we identified. We were told to budget for a survey of 12 acres. That area estimate was clearly on the low side. Our demonstration plan called for surveying the Open Field Area with profiles on 0.5m offsets. We conducted the survey at a normal walking pace of about 0.6 m/sec. Three-component TEM transient data (31 time gates per transient) were acquired at the rate nominal of 32 samples per second. Over most of the survey, cart attitude data including cart heading, pitch angle, and roll angle were acquired at the rate of approximately four samples/sec. GPS position data were recorded at a rate of five samples/sec. This survey was treated in all respects like a production survey with the intent of meeting our demonstration objectives in an efficient and economical way. We had no time to conduct experiments or to vary any of the operating parameters. We included details supporting the experiment design in Section 3 of our final report [6]. An electronic copy of that report is included in the Appendix of this report.

DNT data processing software is built around Geosoft's Oasis Montaj with the addition of specialized functions to handle TEM transients stored in array-valued channels. Processing generally follows the sequence shown in Figure 8. Each block of TEM data is merged with cart location and orientation data and saved in a Montaj database. Oasis Montaj is then used for further data processing and plotting results. Both profile plots and plan-map images are used for quality control. Specialized utility programs may be driven from within Montaj for data filtering, target picking and modeling. Further details on data processing, analysis, and quality control have been included in Section 2.3 of the final report [6] (Appendix). Metadata specifying hardware configuration and data processing parameters are saved in text files accessible by all DNT software. Configuration files are in an Oasis Montaj parameter-block format that can be reviewed and edited with a text editor or with interactive DNT software utilities. DNT programs read default parameter values from configuration (CFG) files and write updated values to provide an archival record of survey configuration and data processing parameters.

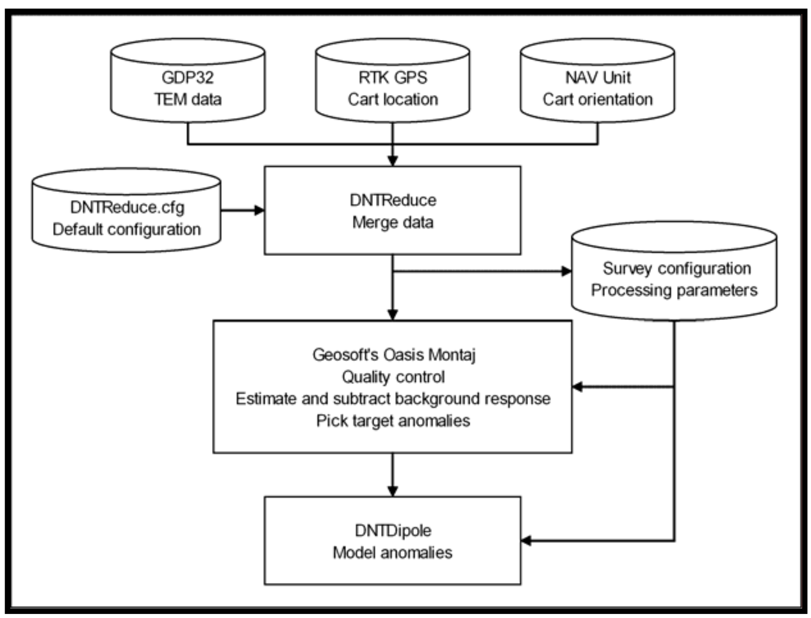

Figure 8. Block Diagram Showing Major Data Elements and Processing Modules in the DNT Data Processing System.

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4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

We have presented numerical results of our performance in Section 2 (Table 1 and Table 2). Those results were extracted from the scoring records generated by ATC [1, 2]. The cited report also includes ROC curves for both the response stage (i.e., target detection), and the discrimination stage (target classification).

Response Stage Performance (Blind Test Grid – Figure 9 shows the receiver operating characteristic (ROC) curve generated by ATC based on ground truth (unknown to Zonge) for the Blind Test Grid. The curve is rather coarse, but to our eyes, it exhibits a sharp knee at about P_d=70% with a P_{ba}=15%. These results are consistent with our in-house ROC analyses (response stage only) based data acquired over the Calibration Lanes (Figure 6) and ground truth provided by ATC. We show that ROC curve in Figure 10.

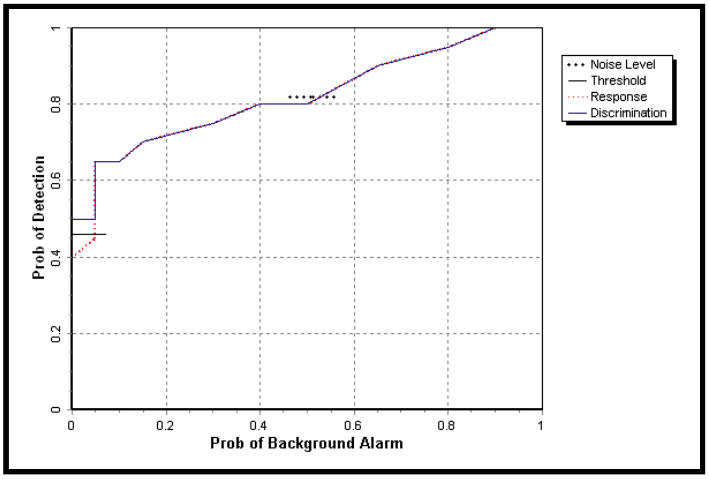

Figure 9. Blind Grid Probability of Detection for Response and Discrimination Stages Versus Their Respective Probability of Background Alarm Over all Ordnance Categories Combined[2].

As stated in our demonstration test plan [13], the overriding performance objective for this demonstration was to "… demonstrate that early time multicomponent TEM measurements significantly enhance the value of broadband EMI measurements for UXO classification." Until we know the performance results from other systems, we cannot make conclusions about whether or not we have met our primary objective. We are disappointed (but not surprised) that our overall P_d score for the response stage is not higher. The ROC curve that we generated from the Calibration Lanes (Figure 10) told us what our P_d score would be even before we formally submitted our target lists for scoring. We were well aware of the depth limitations of the antenna system that we deployed for this demonstration. The ground truth for the Calibration Lanes leads us believe that the P_ds for most, if not all, EMI systems with 1m

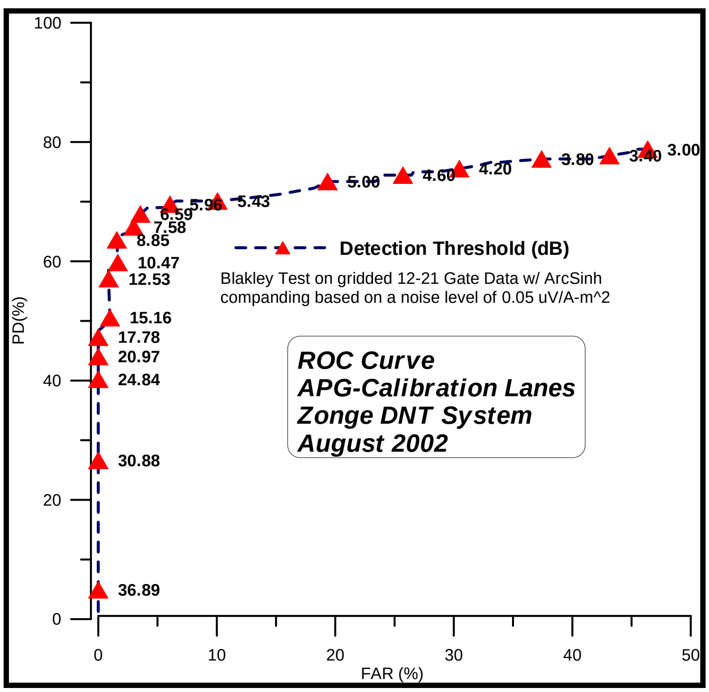

Figure 10. Response Stage ROC Curve Generated from DNT Survey of the APG Calibration Lanes.

antenna geometry demonstrated at Aberdeen or Yuma will be low. Take, for example, the 60mm M49A3 mortar target. The predemonstration testing that we conducted at Blossom Point showed that these targets exhibit a target response with a DNT SNR of approximately 28db when buried at a depth of 50cm. The SNRs for both the man-portable MTADS system (based on the Geonics EM61) and for the EM63 are generally of the same order of magnitude. Moreover, to our knowledge, none of the man-portable EMI systems can reliably detect a 60mm mortar at 1m. Indeed, simple mathematics based on the attenuation of a point dipole response suggests that the EMI signal will attenuate by approximately 36 dB when the depth of burial doubles from 0.5m to 1m. The Calibration Lanes were constructed so that each target was emplaced at 2 depths. At the shallow depth, the target anomaly SNR is typically in the range of 20-30 dB or lower. For the larger targets where shallow target depths are already on the order of 0.5m, when the depth is doubled the steep attenuation with depth (R^{-n} $4 \geq n \geq 6$) guarantees that the target will become undetectable with 1m transmitter loops.[5] In our opinion, the targets in the Calibration Lanes have been emplaced too deep and the ratio between the two target depths should be closer to z_d/z_s = 1.5. This ratio will produce anomaly attenuations on the order of 20db rather than 40dB.

If P_d for deep targets becomes an issue, it is easy enough to increase the moment of the transmitter coil (by adding turns). This will improve the SNR for the larger (and deeper) targets by 6dB or more. It will come at the cost of a somewhat diminished P_d for the small targets that (by ATC's definition) lie at depths less than 30cm.

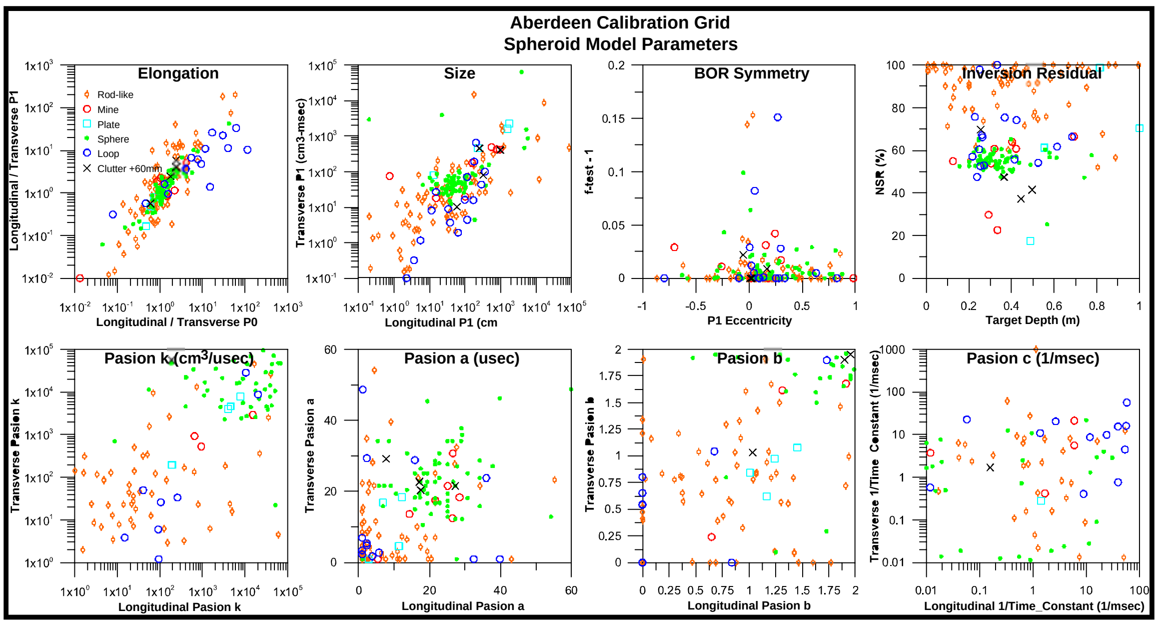

Figure 11. Model Parameters from Inversion of APG Calibration Lane DNT Cart Data with Target (x,y,z,h,p,r) **Fixed at Known Values.**

[5] The reader should examine the Calibration Lane map shown in Figure 6. In particular, the columns with targets identified as 57mm, 60mm, 2.75(Rocket), 81mm (mortar), 105mmM60, and 155mm all have two target positions showing no anomaly that corresponds to positions where the target depth has been at least doubled.

Response Stage Performance (Open Field) – The response stage performance of the DNT system in the Open Field degraded dramatically, dropping from 80% overall (Table 1) to 45% overall (Table 2). This change in performance is inconsistent with the overall quality of the DNT data. In our final report ([6], p.53 and Figure 3.13), we noted a systematic position bias of approximately -19cm in the Northing coordinate when we compared statically obtained positions over our calibration point with corresponding dynamically measured positions. We are unable to explain this bias. But the bias is based on 120 static measurements and a comparable number of dynamic measurements of the position of our calibration target made over a 2-week period. In their Open Field report, ATC provided us with a statistical estimate of the position errors ([1], Table 9, p. 20), presumably calculated from the set of all the targets and clutter that were detected. We reproduce that table here (Table 4) because it confirms our own independent findings concerning the bias in the Northing positions.

Table 4. Location Accuracy (m) **for 4D TEM as Reported by ATC [1].**

	Mean	STD Dev
Northing	-0.16	0.12
Easting	-0.03	0.12
Depth	0.04	0.20

We have corresponded with Larry Overbay (ATC) in an effort to identify the reasons for the poor scores for the Open Field response stage [17, 18]. Larry indicated that the drop in overall response-stage score is consistent with scoring from other systems demonstrated at APG. He also told us that the primary reason for the low response-stage scores was that many shallow targets were undetected. This result is inconsistent with the scores received for our Blind Test Grid target submittals where P_d and P_{fp} were, respectively 100% and 90% (Table 1). Larry also told us that there was only a marginal increase in the P_d from 47% to 51% on standard targets (Table 2) when they increased the allowable radius of detection (R_{halo}) from 0.5m to 0.8m. The increase in R_{halo} is more than enough to account for the bias in position noted by both ATC and us. Therefore, we discount the possibility that our target picks fall outside the target halo due to position errors. Another possible explanation for the change in performance is that we set our detection threshold too high. In the Open Field, the detection threshold was set at a value that was low enough to detect all of the obvious targets plus many others. Thereafter, we inspected each target anomaly in profile form (often at two different gate times) to determine whether the anomaly might be caused by noise. Through this process, many target anomalies were deleted from our target list. It may be that this manual target inspection process was counterproductive since valid targets may have been deleted.

An adequate explanation for the poor score in the Open Field must await the release of the ground truth at the Aberdeen site. With ground truth available, we will have an opportunity to re-inspect the EM responses in both map and profile form. This will allow us to revise our procedures for detection and thereby improve response stage performance.

Discrimination Stage Performance – An important objective of our demonstration has been to demonstrate the added value of 4-D TEM data to the discrimination stage. Demonstration of improved discrimination requires that we go beyond the simple detection of a target anomaly. It requires that we analyze the spatial and temporal behavior of a target anomaly that has 4 independent dimensions (i.e., 3 vector components plus time) and provide estimates about

whether or not the target has the characteristics of UXO. If possible, it is desirable that we carry this analysis further to the extent that we can provide some sort of crude identification or classification of the target. The problem only becomes tractable when we fit all these data to a simple point dipole. Although we diligently applied our modeling program to help us with the discrimination stage of the demonstration, it is clear from the discrimination stage score that we have much to learn before we are able to adequately apply our modeling tool. We think that our final report [6] shows that we have come a long way toward being able to analyze the parameters that are generated by our modeling software (DNTDipole). We summarize some of those results here in the firm belief that they provide definite indications that there is "added value" in our 4-D TEM approach.

Figure 11 summarizes the results of our model parameter estimates from inversion of Aberdeen Calibration Lane data. A large sample of 8 lb shotputs generates good statistics for the response of a permeable, conductive sphere. Longitudinal/transverse P_0 and P_1 seem to hold up as robust shape indicators for spheres, loops, and mines, although UXO with rod-like shapes have a wide distribution of ratio values. In Figure 11, we have used P_1 as the indicator of target size; P_0 (not shown in Figure 11) and Pasion k (lower left graph in Figure 11) are also good size indicators. Inversion residual noise/signal ratios (NSR) are high for all targets in the Calibration Lanes. The plot in the upper right, showing NSR versus target depth confirms what the map already tells us. With a few exceptions (e.g., T62 AT mines), the SNR level of the UXO target population in the Calibration Lanes is marginal for parameterization with models. The low SNR of the target population probably reflects a design objective on the part of ATC to test the limits of detection. To achieve that objective, ATC placed the targets at depths where the anomaly SNR is marginal for good modeling results. Regrettably, that makes the data we acquired in the Calibration Lanes less useful for developing and testing methods for discrimination. Having said that, however, our results show that many parameters, particularly the moments P_0 and P_1 and their ratios are sufficiently robust in that they provide a useful basis for discriminating targets based on target shape and size. The importance of the f-test-1 parameter is shown in the body of revolution (BOR) Symmetry plot in Figure 11 where in this case, the ordinate parameter is f-test-1 (spheroidal model). The f-test-1 parameter is an χ-square statistic ratio on the constrained model.[6] Discrimination based on f-test-1 is therefore similar to the approach outlined in the recent report by Nelson and others [4] on advanced discrimination techniques for use with the MTADS system.

We have applied principles of multivariate discriminate analysis in an effort to choose parameter weightings (eigenvectors, if you will) that group or otherwise categorize populations of target anomalies [14]. In Figure 12, we show how this method of analysis separates targets in the APG Calibration Lanes. The panel on the left is a scatter plot of two discriminate variables (d1,d2) that have been coded with a unique shape and color according to target shape (i.e., rods, disks, loops and spheres). The discriminate variables heavily weight the polarization (*P0_R*) ratio (i.e., similar to the β ratio) and the spheroid f-test-1 statistic. Target discrimination is affected by computing the group that best describes an unknown target in the context of the discriminate variables. We compute a discrimination rank or confidence by determining the distance between the unknown target point and the centroid coordinates for each group. We de-weight the resulting rank using the model fit statistic (NSR) so that anomalies with a poor fit will not

[6] In spheroidal model case, the anisotropic dipole model is constrained so the body has an axis of symmetry that requires two of the principal axes to have identical polarizability.

receive a high rank. In the case of simple shape-based discrimination, we rank our targets against the rod-like target group shown on the left panel in Figure 12. In the right hand panel of Figure 12, we show the ROC curve generated using target ranks generated from the shape-based target analysis illustrated in the left panel. The right hand panel shows a second ROC curve, shape and size. This curve is generated from an expanded analysis that uses target parameters sensitive to target size (principally *P0*). The details of these analyses are beyond the scope of this report. (Refer to our final report [6] for a more complete explanation and additional examples.)

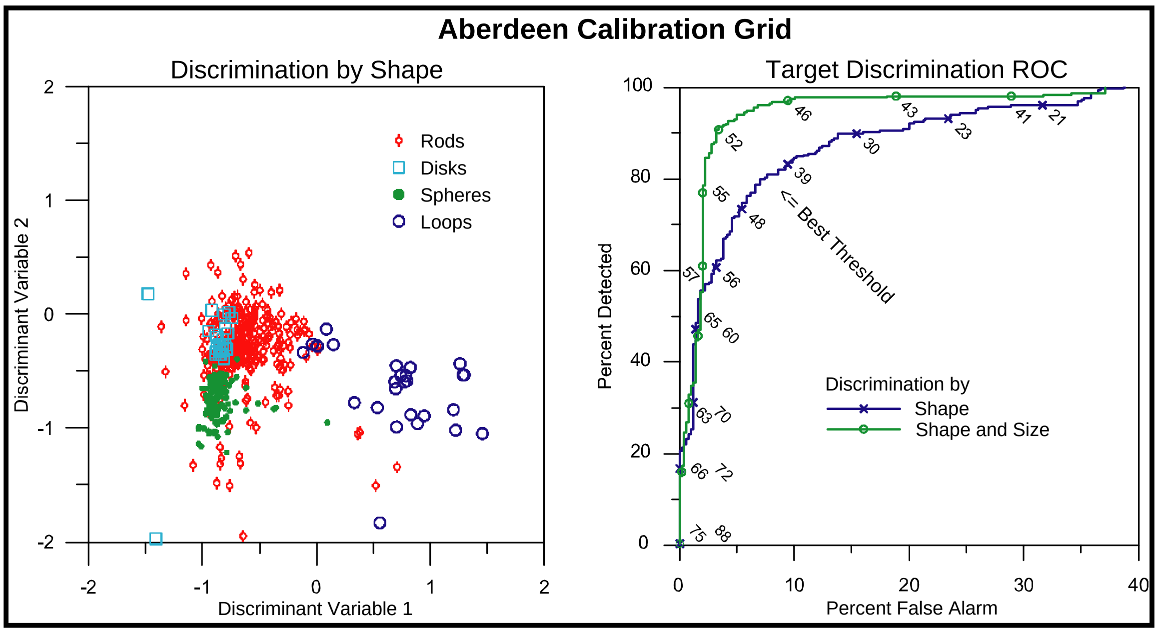

Figure 12. Target Classification at APG Using Shape and Size and Shape-Based Ranking Metrics.

4.2 PERFORMANCE CRITERIA

Performance for the DNT system must be judged against its ability to detect and to discriminate UXO. In the response stage of our demonstration, we had a stated objective of achieving 90% or better P_d as judged both by formal scoring in test areas where the ground truth is held confidential (e.g., everything at APG except the Calibration Grid) or by our own analyses when the ground truth is known. In arriving at that objective, however, we chose a number that was comparable to P_ds achieved by EMI systems and demonstrated at other test sites. Our expectation, therefore, was that the DNT system has a P_d that is comparable with other commonly used EMI systems.

Our expectations for the discrimination stage are purely qualitative. Our stated objective has been to demonstrate that multicomponent TEM will significantly improve our ability to perform model-based interpretation. As in the response stage, performance in the discrimination stage is best judged by preparing a ROC curve. This means that the parameters (of which there are many) for each target must be analyzed and reduced to a number (the rank) reflecting the probability that it is a UXO (i.e., the higher the rank the more probable that the target is a UXO). Using the anisotropic model, we reduce the three transients acquired at each of the field points in

the immediate vicinity of a target (typically 20-40 field points) to three principal polarizability transients. At this point, there are still 93 data points (31 points per polarizability transients). Using the Pasion-Oldenburg parametric model, we further reduce the principal polarizabilities to four parameters. We also compute two moments on each of the polarizability transients (P0, and P1). Thus we end up with 18 model parameters plus the two fit statistics (NSR, and f-test). Clearly there is still a lot of analysis required to distill from these 20 numbers a single number that reflects the probability that the target falls within some classification group (e.g., UXO).

4.3 DATA ASSESSMENT

The response stage score (80%) was assigned by statistical analysis of the target list for the Blind Test Grid submitted to ATC in compliance with rules governing our demonstration. As we have stated herein, we are not in a position to comment on that score until it has been placed in the context of scores for competing systems. In the comparisons we have made heretofore, at Blossom Point and at our own test area near Tucson, the sensitivity of the DNT system has compared favorably with the benchmark EM61 system [15]. At this point we have no reason to believe that the DNT system is either more or less sensitive than competing systems.

Our expectations with regard to the discrimination stage were purely qualitative. Our stated objective has been to demonstrate that multicomponent TEM will significantly improve our ability to perform model-based interpretation. The scores assigned by ATC do not confirm that we have met this objective. But we argue that the poor score (P_d = 45% overall) is more properly a grade that is assigned to our ability to interpret the parametric information generated by our modeling program rather than an indication of substandard performance on the part of either the DNT hardware or software. Analysis methods that we developed subsequent to the submittal of our target lists based on multivariate statistical methods are much more promising. Based on the results we obtained using data and ground truth from the Calibration Lane, we believe that our score for the discrimination stage of the Blind Test Grid would improve significantly if we could submit a revised ranking. Indeed, the ROC curves shown in Figure 12, if they hold true for the target mix in the Blind Test Grid, suggest that we might expect a P_d as high as 80% or more, were we to be scored using shape or shape-and-size ranking metrics. We have formally requested ATC to allow us to resubmit the Blind Test Grid with revised discrimination stage ranks that reflect shape and size discrimination.

4.4 TECHNOLOGY COMPARISON

The closest that we can come to a side-by-side comparison of the DNT system with the competing EMI technology comes from the predemonstration survey conducted at Blossom Point [15]. Data sets from both the EM61 (NRL man-portable MTADS) and the EM63 (Geonics, Ltd) were used to assess the sensitivity of the DNT system for detection relative to these competing systems. Through a comparison of the peak SNRs for each of 74 targets at Blossom Point, we were able to demonstrate that over a broad range of targets at Blossom Point (73 targets), on average the SNR of the DNT was only 1 dB below that of the man-portable MTADS system. The DNT was significantly more sensitive than the EM63. However, we are told that the EM63 demonstrated at Blossom Point was a prototype unit and that later versions exhibit improved SNR values. Using the ground truth from Blossom Point, we have generated ROC curves for both the DNT system and man-portable MTADS system. These ROC curves,

shown in Figure 13, reflect the comparative performance of the two systems during the response stage of UXO detection.

We have no comparisons of the DNT technology with other systems in the discrimination stage. The system is unique. It would be possible for us to compare the DNT system with the EM63 in the discrimination stage. However, as Nelson and others [4] have noted, reliable model-based interpretations using systems with a single receiver coil require the analysis of a data set consisting of a composite data set formed from two surveys acquired in orthogonal directions. This requirement results from the need to have enough data points within a small radius (typically 1m) of the target position to affect a robust modeling solution. The data set for the EM63 at Blossom Point consists of data acquired along lines at 0.5m spacing in the N-S direction only. Thus, there are insufficient data points around each target to perform the modeling.

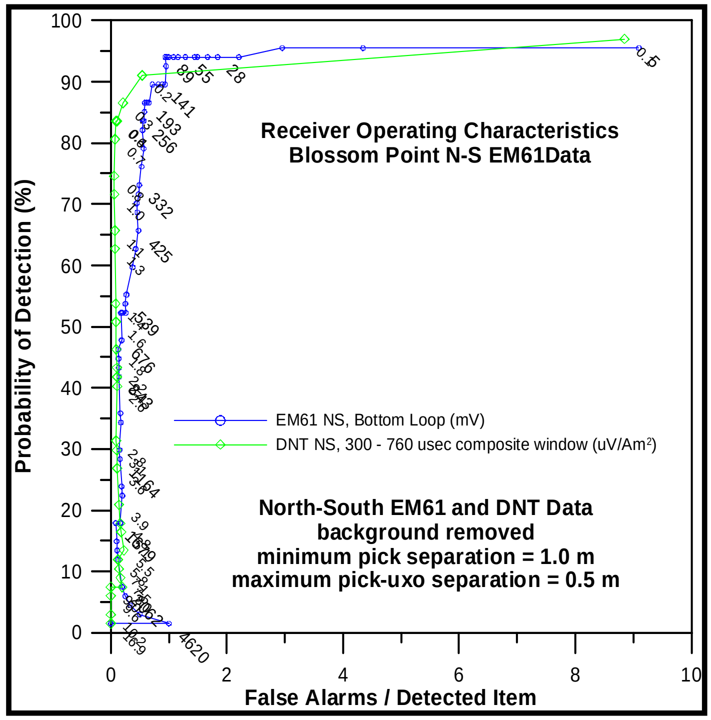

Figure 13. Response Stage ROC Curve for the DNT and EM61 Systems. (Blossom Point, December 2001)

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5.0 COST ASSESSMENT

The costs involved in conducting the demonstration at the standardized site at the ATC are very useful in estimating both the productivity and the costs involved in the routine implementation of the DNT technology. Table 5 lists the total costs that Zonge incurred from activities related to preparation, mobilization/demobilization, data acquisition, and data processing for this demonstration.

Table 5. ATC Demonstration Expenses.

Cost Category	Labor	Travel and Per Diem	Miscellaneous Expenses	Shipping	Equipment Amortization	Totals
Mob/demob	$4,680	$3,299	$349	$2,134		$10,462
Field data acquisition	$20,234	$5,195	$600		$2,550	$28,579
Data QC and interpretation	$36,952					$36,952
Totals	$61,866	$8,494	$949	$2,134	$2,550	$75,993

A few comments on the demonstration costs listed above are warranted since they impact on our cost projections for a similar job as this technology is being implemented commercially. The cost of this demonstration is higher than our projection for a similar job in the future. The labor charge is inflated for all cost categories because of the involvement of the principal investigator (Snyder) in all phases of the operation and the involvement of the principal scientist (MacInnes) in the data QC and interpretation category. In regard to the latter, significant software development was conducted during the 30-day period between the demobilization of the crew (9/2/03) and the deadline for the submission of our target lists (10/2/03). Partially offsetting the high labor costs, however, is the fact that the charge for the amortization of capital equipment does not fairly reflect the cost of that equipment. We believe that the cost of data QC and interpretation can easily be reduced 50% in routine deployment. Similarly, we can expect reductions of approximately 20% and 10%, respectively, in labor costs for data acquisition, and mobilization and demobilization during a routine deployment of the technology. The cost of the demonstration was approximately $12,000/ha ($4,800/acre).

We have refigured the costs for a hypothetical 6 ha (~15-acre) job similar to the APG Standardized site. The costs are based on an average daily production of 0.4 ha/day (1 acre/day) with a crew of three people in which the principal investigator has been replaced with a site geophysicist. Likewise, the responsibility for data QC and interpretation has been devolved to a senior staff geophysicist.[7] Note, however, that we have increased the travel expenses to reflect working a 5-day workweek, and we have added cost for amortization of capital equipment.[8] We report those costs in Table 6.

[7] The project geophysicist will continue to be responsible for initial field QC before the data are transported to the Zonge office for complete processing and interpretation by the senior staff geophysicist.

[8] During the demonstration at APG, we worked straight through, thereby saving on per diem expenses.

Table 6. Estimated Job Costs for a Hypothetical DNT Survey of a 6 ha (15-acre) **Site.**

Cost Category	Labor	Travel and Per Diem	Miscellaneous Expenses	Shipping	Equipment Amortization	Totals
Preparation	$1,220		$220			$1,440
Mobilization	$1,400	$1,375		$1,320		$4,095
Field data acquisition	$20,996	$7,837	$1,870		$8,775	$39,478
Data QC and interpretation	$6,629					$6,629
Demobilization	$1,071	$1,265		$1,320		$3,656
Totals	$31,316	$10,477	$2,090	$2,640	$8,775	$55,298

Table 6 suggests that were we to treat the demonstration survey at APG as a routine job now, we could reduce the total survey cost by 13% or more. Moreover, these estimates imply that the incremental cost of additional data acquisition and interpretation (i.e., cost per area, exclusive of preparation, mobilization, and demobilization) is $7,700K/ha ($3,100K/acre).

5.1 COST ANALYSIS

It is clear from the cost breakdown estimate given in Table 6 that the cost of data acquisition is the most important factor controlling the unit cost of UXO surveys. That cost is approximately $3,100K/acre. The cost for data QC and interpretation ($500/acre) is small by comparison. Daily production with the man-portable DNT system can only be improved by increasing the survey line separation. This is not an option if the system is to be used for discrimination. However, if the only purpose of the survey is to detect anomalies, we can increase daily production by 20% by changing the offset interval between survey lines from 0.5m to 0.6m (2 ft). This would increase the daily survey production to 1.2 acres/day and drop the unit cost of a DNT survey to less than $2,600K/acre. We maintain that this small change in survey line interval would not significantly change P_d (response stage) since the DNT system data stream includes both the vertical field component and the horizontal components as well. The cross-track horizontal field component, in particular, is useful in determining the offset direction to the target [16] and hence helps to ensure that the target is not only detected but is also properly located. If DNT is used purely for target detection, an additional cost savings (perhaps as much as $250/acre) would be realized because the level of effort in the data QC and interpretation task is significantly reduced since target modeling with DNTDipole is no longer necessary.

5.2 COST COMPARISON

The field services division of Zonge Engineering has conducted a number of UXO site surveys using the baseline system, the EM-61. Therefore, we are in an excellent position to compare the operating costs of acquiring EM-61 data for both detection and shape-based interpretation. As we indicated in Section 3 of this report, we regard the EM-61 MkII as a baseline system against which we can compare the performance of DNT. In making that comparison, we accept the NRL's conclusion that satisfactory modeling requires that the area under investigation be surveyed twice with orthogonal surveys [4].

We have had recent experience with the interpretation of EM-61 MkII data with our proprietary modeling program DNTDipole. We treat the four time gates acquired from the coincident

receiver as a coarsely sampled TEM transient. Thus, the EM-61 MkII can be treated as a single-component multigate system—sort of a poor-man's EM-63. The capital cost of the EM-61 MkII is considerably less than that of the DNT system ($20,000 versus $50,000), which reduces the daily operating cost by approximately $200/day. Offsetting the lower equipment cost is the need to survey the area twice (in orthogonal directions) to adequately sample target anomalies to permit satisfactory shape-based modeling and discrimination.

Table 7 contains a cost breakdown for the hypothetical 6 ha survey that we previously estimated with the DNT system (Table 6) but now surveyed in orthogonal directions with the EM-61 MkII and processed both for target detection and target classification using DNT processing software. These tables confirm that regardless of how the equipment is amortized, the main cost element in these UXO surveys is the cost of labor. If we ignore for the moment the obvious performance advantages for classification of the DNT system, the added cost for the EM-61 MkII survey when deployed for both detection and discrimination is due almost entirely to the need for double the survey coverage. To put it another way, single coverage (i.e., profiles in a single direction) with EM-61 MkII survey works well for detection but will not permit reliable model-based interpretation. At the cost of an additional $500/ha ($200/acre), the DNT survey can be used for both detection and model-based interpretation.

Table 7. Estimated Job Costs for a Hypothetical EM-61 MkII (bidirectional) **Survey of a 6 ha** (15-acre) **Site.**

Cost Category	Labor	Travel and Per Diem	Miscellaneous Expenses	Shipping	Equipment Amortization	Totals
Preparation	$1,220		$220			$1,440
Mobilization	$2,800	$2,110		$1,320		$6,230
Field data acquisition	$41,995	$21,630	$3,300		$18,390	$85,315
Data QC and interpretation	$10,606					$10,606
Demobilization	$2,142	$1,975		$1,320		$5,437
Totals	$58,763	$25,715	$3,520	$2,640	$18,390	$109,028

In Table 8, we summarize and compare estimates of the daily cost and the unit production costs for a crew equipped with an EM61 MkII and a DNT system. All labor costs, mobilization/demobilization are the same. The estimated daily crew rate reflects only the difference in the capital cost of the equipment.

Table 8. Comparative Daily Crew Rates and Production Rates for Comparably Equipped and Manned Crews Operating Either the EM61 MkII or the DNT System.

Cost	EM61 MKII	DNT	Comment
Daily production cost	$3,197	$3,539	
Response Stage Only			2-ft line spacing (both systems)
Cost/acre	$2,500	$2,785	
Response + Discrimination Stage			1/2-m line spacing. EM61 data acquired in orthogonal directions
Cost/acre	$6,394	$3,539	

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The cost analysis presented in the previous session shows that the marginally higher cost for deploying the DNT system is the result of increased capital cost together with an increased labor cost for data processing. But the DNT system is actually less expensive to deploy than the baseline EM61 system when it is required that the target list be ranked in the response stage and the discrimination stage as well. When the two systems are deployed for target detection only (response stage), the cost of the DNT system is approximately 10% higher, reflecting higher capital cost.

In routine UXO surveys where the objective is response stage characterization, a common practice is to gang two EM61 together into a single instrument that covers a 2m swathe. This practice doubles the production rate without increasing the labor. The only added cost is the cost of a second EM61. With its ability to simultaneously measure 3 independent receiver antennas, the DNT system can be deployed in the same way without requiring a set of duplicate instrumentation. The only requirement would be the construction of a different antenna platform. Under this scenario, the daily crew cost and the unit cost of production ($/acre) for the DNT system would compare quite favorably with that of a crew equipped with a pair of EM61 that are ganged together.

6.2 PERFORMANCE OBSERVATIONS

It is unfortunate that we were the first to demonstrate at the Aberdeen test site because we have no benchmark against which to compare our performance. We have commented that we are disappointed in our overall P_d (80%) score for the response stage. The scores suggest that failure to detect many "deep" targets explains the low score. We commented in Section 4.3 that we have demonstrated that the DNT system has a sensitivity that is comparable to other man-portable systems over a broad range of targets, so we trust that scoring of competing systems will have similar scores. The response stage performance table (Table 1) shows that the DNT system P_d performance for shallow (< 30cm) targets is 100% while it is only 10% for deep (>1m) targets. The excellent performance for shallow targets can be attributed to the broader bandwidth of the DNT system (i.e., "fast" TEM) as compared with the EM61. Improving the performance of DNT system for targets at intermediate and deep depths is a simple matter of increasing transmitter moment. No mechanical change in the DNT system is required to make this adjustment and there would be no change in the system cost. But such a change will result in a diminished performance for small shallow targets. We think it best to wait until we know the scores for other systems that have been deployed over the Blind Test Grid at APG before we make any modifications to the DNT transmitter antenna.

We have already commented in some detail on discrimination stage performance. We wish to emphasize that, because of the multicomponent nature of the DNT system, we are able to apply our physics-based modeling software on data consisting of a single set of data profiles and thus rank targets for the discrimination stage. Competing systems such as the EM61 MkII and the EM63 require that the area be surveyed in orthogonal directions before a comparable analysis can be completed. This gives the DNT a definite cost advantage provided the modeling techniques such as we apply are effective in ranking the target list. Our recent work on

discrimination based on multivariate statistics that we have applied to data sets from Blossom Point and from the Calibration Lanes suggest that we can do much better than the scores for the discrimination stage at APG for the Blind Test Grid (Table 1) seem to imply. Those scores do not reflect these new methods of analysis. In any case, ability to reliably discriminate between UXO and clutter remains to be independently verified.

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APPENDIX A

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2. ATC Scoring Report—Blind Test Grid ***ATC8642_SR37_BlindTestGrid.pdf***
3. ATC Scoring Report—Open Field ***ATC8675_SR38_Open Field 31804.pdf***

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